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Four Sediment Cores from the Continental Shelf Outside Trøndelag

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Grain size analysis and clay mineral investigations have been carried out. The cores consist of an assemblage of sand, silt and clay, where the clay content is gradually decreasing from the bottom towards the top of the cores. The main mineral constituents of the clay fraction are illite, kaolin, mixed layer-minerals, chlorite, quartz and feldspar. The sediment is assumed to consist of material washed out from the till deposits at the shallower parts of the shelf. The kaolin content of the clay fraction varies between 10 and 30% and has probably been derived from the sedimentary rocks underlying the glacial deposits.

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Introduction

The present paper is the result of investigations of four sediment cores from the continental shelf outside Trøndelag, Western Norway (Fig. 1). The paper is a part of a cand.real. thesis presented at the University of Bergen (Haldorsen 1972). A few later laboratory investigations have been added. The work is a part of a regional investigation of the surface sediments on the Trøndelag shelf, carried out at the Geological Institute of the University of Bergen under the leadership of Professor H. Holtedahl.

The map (Fig. 1) shows the location of the Trøndelag shelf. The bottom topography is characterized by the two bank areas in the north and south, respectively named Haltenbanken and Frøyabanken, the most shallow parts of them situated 100–200 m below present sea level.

These two shallow bank areas are separated by a deeper region from which the four investigated cores have been collected (Nos. 304, 309, 324 and 350 in Fig. 1). The depth of this region is about 300 m. This deep region continues towards the northeast and southwest and separates the two bank areas from the skerry area. As can be seen from Fig. 1, the four cores have been collected outside the mouth of Trondheimsfjorden. The sampling localities lie between 10 and 90 km NW of the Island of Frøya. The depth along this northwestern-southeastern profile varies between 310 and 330 m.

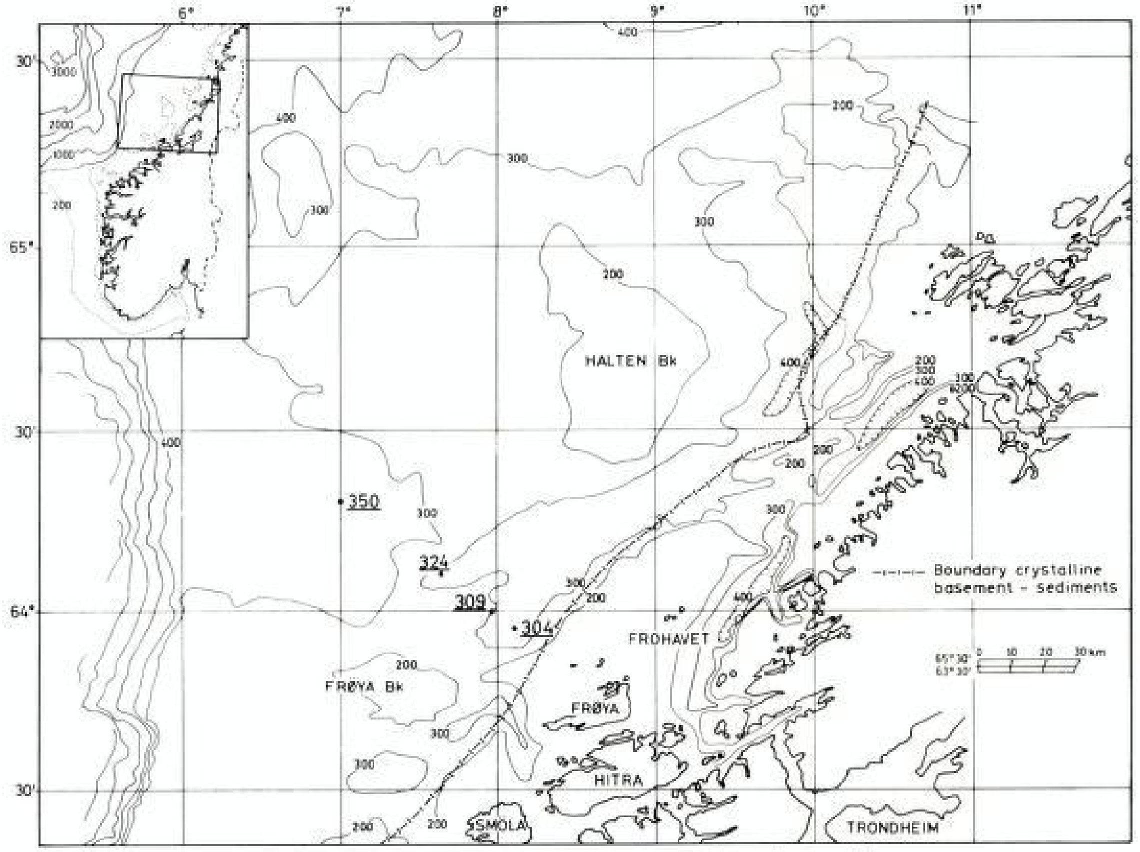

Fig. 1. Map of the shelf area outside Trøndelag. Underlined numbers refer to the localities of the investigated cores. Boundary between crystalline basement and sediments after Holtedahl & Sellevoll (1971, p. 46.)

Previous investigations of the area

Investigations of the Trøndelag shelf have been summarized by Holtedahl & Sellevoll (1971). This shelf area consists of a crystalline basement which is covered by several thousand metres of rather soft, sedimentary rocks of presumed Mesozoic and Tertiary age. The thickness of the Quaternary sediments varies from 250 m on the Haltenbank to about zero in the area from which the four investigated cores have been collected. The composition of the gravel fraction of the surface sediments indicates that the ice, at least once during the Quaternary, advanced across the Trøndelag shelf, leaving a glacial till which now covers the greater part of the surface in this area (Holtedahl & Sellevoll 1971, p. 47).

The lithological composition of till samples from the region where the four cores have been collected is of special importance. There is a considerable content of soft, unmetamorphosed rock fragments, which are not derived

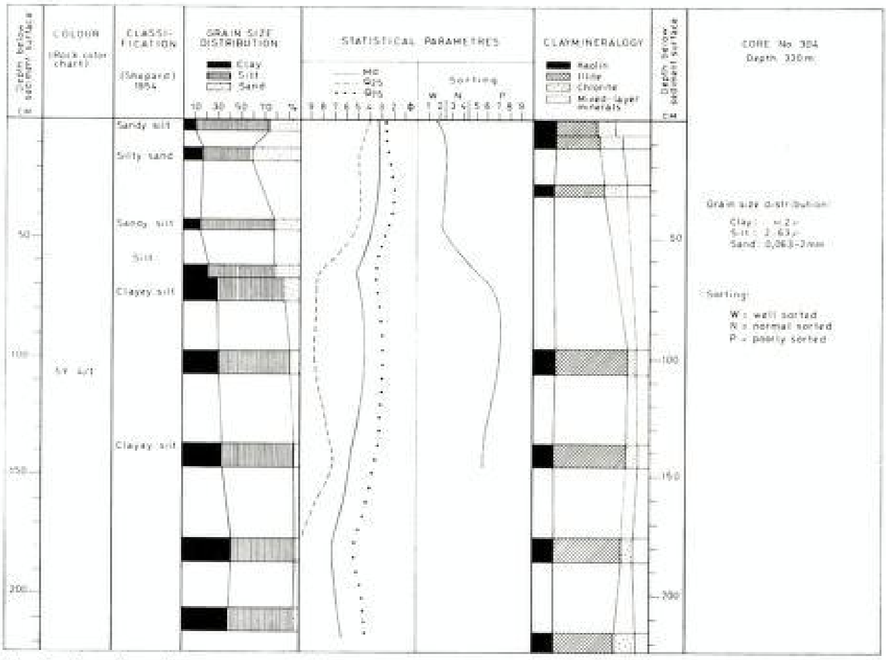

Fig. 2. Results of investigations from core No. 304.

from the coastal land areas. Fossil records indicate a Mesozoic age for some of this material (Holtedahl & Sellevoll 1971, p. 47).

Fig. 1 shows the assumed boundary between the crystalline rocks which form the coast areas, and the unmetamorphosed sedimentary rocks which cover the shelf area (Holtedahl & Sellevoll 1971, p. 46). This boundary is situated close to the coastal islands on this part of the Norwegian continental shelf.

Sampling procedure and description of the material

The examined material was collected with a gravity corer during 1969 on a cruise in the research vessel *Johan Hjort* belonging to the Institute of Ocean Research, Directory of Fisheries, Bergen. The examinations took place during 1970 and 1971. The material was kept in airtight PVC-tubes until the laboratory investigations were carried out.

On Figs. 2–5 are shown data from the four cores. The lengths vary from 60 cm for core No. 350 to 240 cm for core No. 309. The colour and texture are nearly identical for cores Nos. 304, 309, 350 and the upper part of core 324, while the lower 50 cm of core 324 consists of a sediment which differs from the upper 100 cm of the core with respect to colour, grain-size distribution and mineralogy (Fig. 4). This sediment is thought to be a till mainly composed of material derived from the Mesozoic and Tertiary bedrock. It is

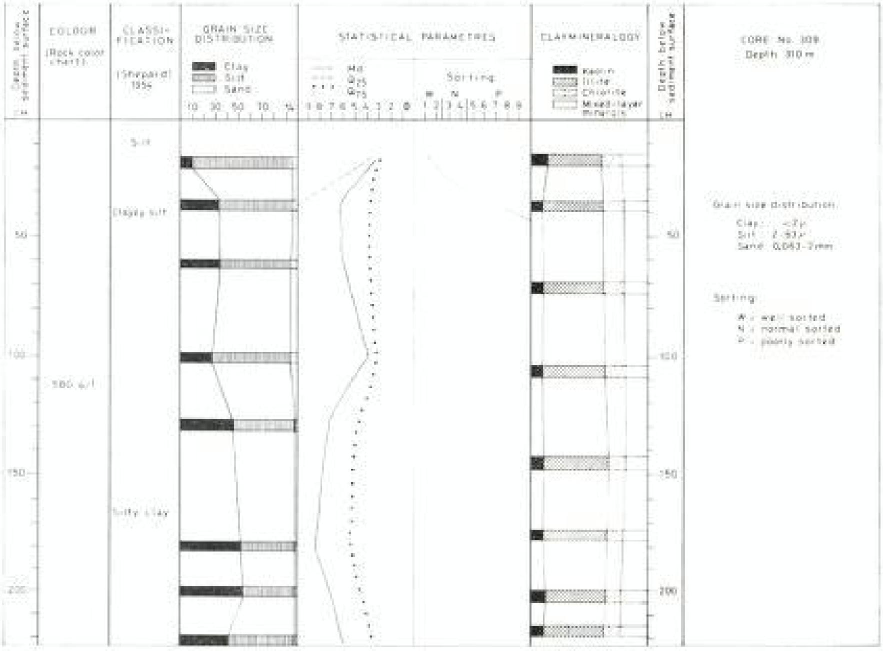

Fig. 3. Results of investigations from core No. 309.

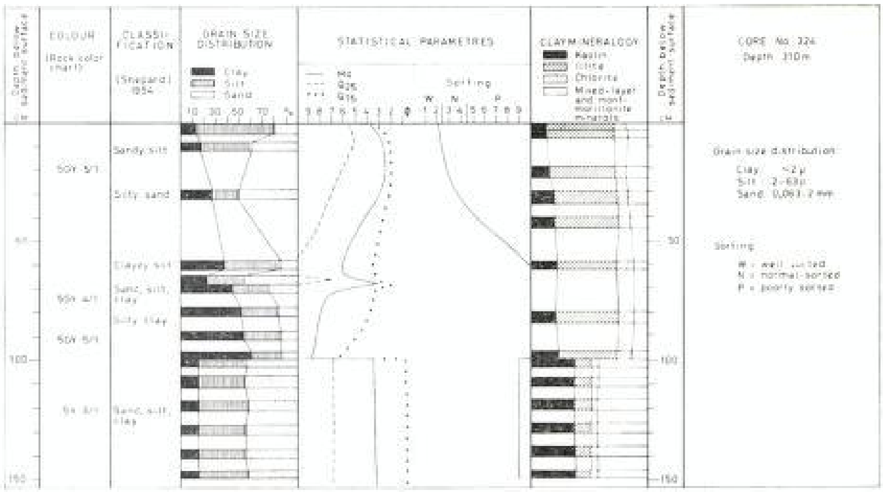

Fig. 4. Results of investigations from core No. 324.

discussed by Holtedahl et al. (1974) and will not be further described in this paper.

The colour of the cores is grey to bluish green and the colour symbols in Figs. 2–5 refer to the Rock Color Chart (Geological Society of America 1951). The cores consist mainly of silt and clay with variable proportions of

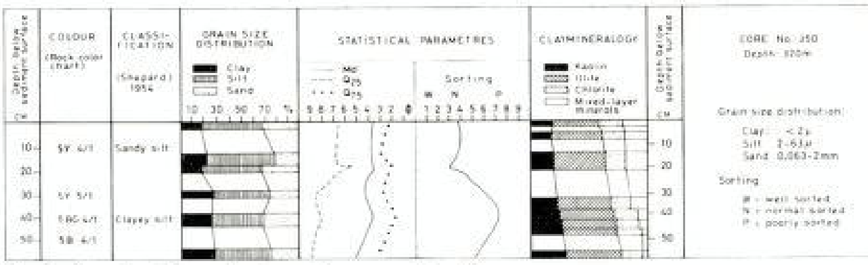

Fig. 5. Results of investigations from core No. 350.

sand. The material coarser than 2 mm consists of shell debris; the weight per cent of this fraction is negligible.

Foraminifera and shell fragments are found through all the cores, most frequently in the upper parts, while there are only small quantities in the deepest parts.

The shear strength values vary between 0.2 and 1.5 t/m^2 and the sensitivity is about 2–3. This rather soft sediment therefore shows no signs of overconsolidation.

The porosity values vary from 50 to 60%.

Laboratory methods and results of investigations

GRAIN-SIZE DISTRIBUTION

After removal of salt pore water from the samples, grain-size analysis was carried out by sieving and pipette methods. Samples were taken from each, tenth to twentieth cm through the cores, and about 10 g material was used for the pipette analysis.

The grain size distribution of the four cores is shown in Figs. 2–5. The size grades are mainly classified according to the system of Wentworth (1922); the boundary between clay and silt, however, is placed at 2μ (9 Θ-units). The quartiles Q_1 and Q_3 are the size values used by Pettijohn (1957, p. 37). The sorting is calculated according to Trask (1932).

There is a gradual increase in the clay content from the top towards the bottom of the cores, though the rate of this increase is not the same in all the cores. The greatest increase is found in core No. 324, were the clay content at the top of the core is 10% while the content of clay 100 cm below the sediment surface is about 60%. In this core there is a sand layer at about 20%. The least distinct increase in the clay content is found in core No. 350, which is also the shortest of the four cores. The clay content at the top of this core is about 20% while at the bottom there is about 30% clay.

There is a decrease in the sand content towards the bottom of the cores. The foraminifera in the cores are thought to be benthonic organisms found *in situ* and they have been separated from the sand fraction by using the method described by Feyling-Hansen (1958, p. 39). The weights per cent of the sand fraction in Figs. 2–5 are then calculated for the mineral material. The variation in the sand content is not as distinct as the increase in the clay content, with the exception of core 304. The upper 30 cm of this core consists of about 30–40% sand, while the sand content decreases to about 5% at the bottom. The lowest sand content is found in core 309, where it does not exceed 5% at any level.

The upper 30 to 50 cm of the cores consists of a well to normally sorted sediment, while the sorting is poor in the lower part of each core.

According to the classification of Shepard (1954), the upper part of the cores consists mainly of sandy silt and silty sand, the central part of clayey silt, and the bottom of the cores of a silty clay.

CLAY MINERALOGY

The clay fraction from eight levels in each core has been subjected to X-ray diffraction analysis. A Philips diffractometer with a Ni-filtered Cukα radiation and a goniometer speed of $\frac{1}{2}°2\Theta$ per minute was used. The samples were made by sedimenting an aqueous suspension on a glass slide and drying in air at room temperature. The mineral constituents were mainly identified according to the criteria used by Brown (1961). In addition, the 'slow scan' method of Biscaye (1964a) was used to identify kaolin minerals in the samples. The 'slow scan' speed was $\frac{1}{8}°2\Theta$ per minute. By this method the (002) reflection of kaolin at 3.58 Å can be separated from the (004) reflection of chlorite at 3.54 Å. Fig. 6 shows a 'slow scan' of the 3.5 Å peaks above the correspondng peaks on the 'normal scan' diffractogram from core 309, level 200 cm below the sediment surface.

The principal mineral constituents in the four cores are illite, kaolin, mixed layer minerals mainly of an illite/vermiculite type, chlorite, quartz and a proportion of feldspar. Fig. 6 shows the diffractometer tracings of untreated, glycerol-treated, heated and HC1-treated specimens from core 309, level 200 cm below the sediment surface. In addition to the treatments indicated in Fig. 6, a heating to 300°C was used to identify the mixed-layer minerals in some samples.

The semi-quantitative valuations of the mineralogical composition have been done using the methods of Gjems (1967) and Biscaye (1964b). The content of quartz and feldspar has not been estimated.

The kaolin and chlorite content was determined by treating the samples with a 6 N HC1, and then calculating the ratios between the 7 Å peaks on untreated and HC1-treated samples. The HC1-treatment is also used to determine whether the illite is of a di- or a trioctahedral type. The quartz reflection at 4.26 Å was used as an internal standard.

Figs. 2–5 shows the clay mineral composition of the four cores. The contents are given in the form of bars which show how the intensity ratios of the different clay minerals vary from sample to sample through the cores.

The illite content varies between 30 and 50% in the cores, and illite is

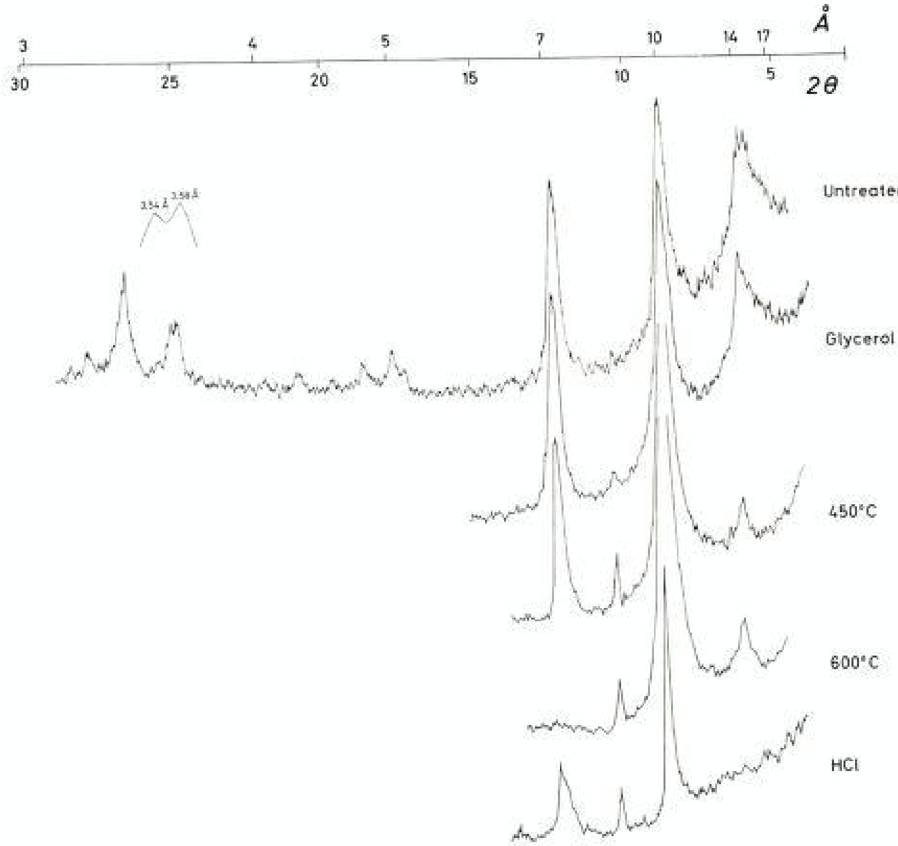

Fig. 6. X-ray diffractograms of core 309, level 200 cm below the sediment surface. 'Slow scan' of the 3.5 Å peak is traced above the corresponding peak of the 'normal scan' diffractogram.

therefore the main mineral group in the four cores. The intensity ratios between the first order reflection at 10 Å and the second order reflection at 5 Å is 1:5 to 1:8, which should indicate a proportion of trioctahedral illite (Bradley & Grim 1961), but the 10 Å reflection, however, is only slightly reduced by the strong HC1-treatment. The illite is therefore thought to be mainly of a dioctahedral type.

The kaolin content varies between 10% at the top of the cores and 20–30% at the bottom. Core 309 has the lowest kaolin content. The highest values are found in core 350, where a distinct increase is also found in the kaolin content towards the bottom of the core.

The chlorite has weak (001) and (003) reflections and strong (002) and (004) reflections. An increase is observed in the intensity of the (001) reflection on heated specimens for three samples (core 304, level 97–107 cm; core 325, level 95–100 cm; and core 325, level 55–58 cm). The low ratio between the (001) and the (002) reflections seems to be rather usual for chlorites in the clay frtction of marine sediments (Biscaye 1964b, pp. 35–

36). The chlorite content varies between 10 and 20%, and no systematical variations are found with respect to depth below sediment surface.

The content of mixed layer minerals varies between 5 and 20%, the highest values being found in the top of the cores.

Discussion and conclusions

SOURCE MATERIAL

The main surface sediment on the continental shelf outside Trøndelag is glacial till (Holtedahl & Sellevoll 1971, p. 44). Besides a mineralogical study of the sand fraction (Bjerkeli 1972), lithological investigations of this till material have until now been restricted to a description of the gravel and stone fraction. A clear dominance is found of crystalline rock types derived from the mainland in the east (Holtedahl & Sellevoll 1971, p. 34). No systematic investigations have been carried out to examine the clay fraction of the till or the composition of the soft sedimentary rock fragments.

One till sample from the area where the four cores have been collected has, as mentioned, a special composition. It is composed of material which most probably is derived from the underlying rocks. Rock fragments from this sample have been subjected to X-ray diffractometer analysis. The most common rock types were silt- and claystones. They showed a kaolin content varying between 60 and 80%.

When the ice advanced across the Trøndelag shelf during the Pleistocene, the soft sedimentary bedrocks were exposed to erosion. These rocks seem to consist partly of silt- and claystones, which are easily disintegrated. The finest fractions of the till have thus been enriched by the minerals from these silt- and claystones. If the rock types which have been analysed are representative of the composition of the eroded bedrocks, it is reasonable to presume that the clay material of the till deposits contains a great part of kaolin minerals.

With the exception of the lower part of core No. 324, the sediment described from the four cores is definitely not till material. This is clearly seen from the grain size distributions and from the distribution of the different foraminifera species through the cores. No systematic analysis has been carried out of the foraminifera in the cores, but a gradual change was observed from a fauna dominated by *Nonion labradoricum, Elphidium incertum clavatum,* and *Virgulina loeblichi* at the bottom, to a fauna represented by *Uvigerina peregrina, Höglundina elegans, Hyalinea balthica, Nonion barleeanum* and *Bulimina marginata* at the top, indicating a climatic change from cold to warmer.

The clay mineral analysis of the four cores showed a kaolin content varying between 10 and 30%. Berry & Johns (1966) have investigated sediment core samples from the North Atlantic Ocean and conclude that the clay minerals are mainly derived from terrestrial sources. Biscaye (1964b) has drawn the same conclusions from investigations of deep-sea cores from the Atlantic

Ocean. The formation of clay minerals *in situ* on the ocean bottom seemed to be of little importance.

The kaolin content of the investigated material cannot be explained by any significant transport of this mineral from the land areas during Postglacial time. Gjems (1967, p. 404) postulates that the occurrence of kaolin in the Scandinavian soils is restricted to places where this mineral is also found in the neighbouring bedrocks. In Norway such kaolin-bearing rocks have very restricted local occurrences and are not of any regional importance. It must be expected, however, that weathering products formed in Preglacial time had another mineralogical composition than most of the surface sediments found in Norway today. The greater part of those old weathering products were removed from the land areas during the Pleistocene and were deposited somewhere outside the Norwegian coast. Some part of that material may be found in the surface sediments on the continental shelf today. The shelf areas have, however, been exposed to glacial erosion, and the old weathering products have most probably been transported further out. Large masses of fresh rock material have been removed from the adjacent land areas and it is not probable that the pre-Quaternary weathering products have any strong influence on the composition of the present shelf surface sediments.

No samples have yet been collected from the shelf inside the boundary between the crystalline basement and the soft sedimentary rocks (Fig. 1). A sediment core collected in the outer part of Orkdalsfjord west of Trondheim (Fig. 1) did not contain any kaolin. Another core taken just outside the mentioned rock boundary, NW of the Island of Frøya, has been analysed and showed a clay mineral composition similar to the material described in this paper. It is therefore most likely that the sedimentary rocks of presumably Mesozoic or Tertiary age, which compose the base for the Quaternary sediments, have been the source material for the kaolin in the sediment cores.

The highest kaolin content found in the clay fraction of the cores studied is about 30%. If a kaolin content of about 60–80% is representative of the sedimentary bedrocks, at least one half of the clay fraction of the most kaolin-rich horizons in these cores consists of material derived from the local bedrocks.

THE TRANSPORT MECHANISM AND TIME OF DEPOSITION

The development of the foraminiferal fauna may indicate that the deposition of the lower parts of the cores took place under more arctic conditions than the deposition of the surface sediments. Suspended material from the melting shelf ice could then be expected to have a strong influence on the material which was first deposited. However, the clay mineral composition of the core material casts doubt on this hypothesis. When the front of the shelf ice was situated inside the boundary between the sedimentary rocks and the crystalline basement (Fig. 1), the suspended material from the meltwater presumably did not contain any significant quantity of kaolin minerals. The mentioned core which is sampled near this boundary west of Frøya has about the same grain size distribution and clay mineral composition as the four investigated cores and is undoubtedly deposited in the same way. It contains about 20–30% kaolin from the bottom to the top. Consequently the main source of the core material does not seem to be suspended material from the meltwater.

Holtedahl & Sellevoll (1971, p. 47) mention that clay and silt material winnowed out from the more shallow parts of the shelf might have been deposited at deeper parts of the area. The material described in this paper may be of such a type. The main part of the core sediments is then redeposited till material washed out from the shallower parts of the shelf. This hypothesis can explain the variations in texture and why the core material contains so much kaolin.

During the Pleistocene the sea level at the Trøndelag shelf showed great changes (Holtedahl 1971). The magnitude of the current- and wave-erosion at the different parts of the shelf was therefore more or less extensive. Calculations of the sea level changes during the Weichselian and Postglacial times are complicated because the isostatic factor is unknown.

What is known, however, is that the shallow parts of the shelf were exposed to erosion. The finest fractions of the till material were winnowed out from these areas.

A determination of the content of foraminifera in the coarse fraction of the cores showed that there was a large increase in the ratio of foraminifera-shells/mineral-grains from the bottom towards the top of the cores, which cannot only be explained by an increase in the frequency of living organisms. The rate of sedimentation seems to have been decreasing during the time of deposition, and this may be explained by decreased erosion of the till material. The eroding power may have been less extensive, or there was also a decrease in the amount of material available for erosion.

The quantitative changes of the erosion and the mechanisms of the transportation can to some extent explain the vertical variation in the grain size distribution. The different size fractions were not transported in the same way. Clay and silt were transported in suspension down to the deepest parts of the shelf area and were deposited there, while the greater parts of the sand and possibly the coarsest part of the silt fraction were transported along the bottom. The bottom transport was a much slower way of transportation than the transport in suspension, and as a result, clay and silt were thereby enriched in the sediments first deposited. When the erosion diminished, the transportation of clay and silt from the shallow areas decreased, while the sand and coarse silt were still in transportation along the bottom down to the deeper parts of the area, giving a higher content of these size fractions towards the top of the cores.

The time of deposition has not been exactly determined. As mentioned, no systematic investigation of the foraminifera content has yet been carried out. The fauna at the bottom of the cores, however, points to a late Weichselian age with arctic conditions. The changes in the fauna may indicate that the environment gradually became more boreal and the deposition of the upper part of the cores took place during Postglacial time. It has not been possible to determine whether the sedimentation is still going on. An investigation of the foraminifera content may possibly answer this question.

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